Energy in Buildings and
Communities Programme

International Energy Agency

Total Energy Use in Buildings: Analysis and Evaluation Methods (Annex 53)

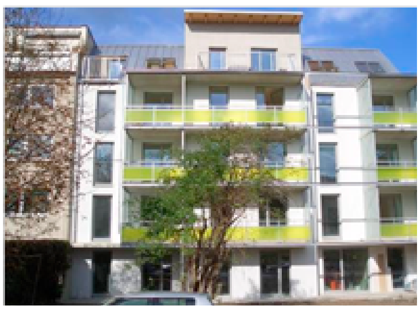
Project Summary Report

June 2016








EBC is a programme of the International Energy Agency (IEA)

EBC

Energy in Buildings and Communities Programme

International Energy Agency

Total Energy Use in Buildings: Analysis and Evaluation Methods (Annex 53)

Project Summary Report

June 2016

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Cover picture: EBC Annex 53 project case studies
Source: EBC Annex 53

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Project Summary

Project Objectives

One of the most significant barriers for substantially improving the energy efficiency of buildings is the lack of knowledge about the factors determining the energy use. There is often a significant discrepancy between the designed and real total energy use in buildings. But, the reasons for this divergence are generally poorly understood and often have more to do with the role of human behaviour than with building design. This discrepancy can lead to misunderstandings and miscommunication between the parties involved in the topic of energy savings in buildings. In general, building energy consumption is mainly influenced by six factors:

1. climate,
2. building envelope characteristics,
3. building services and energy systems characteristics,
4. building operation and maintenance,
5. occupant activities and behaviour, and
6. indoor environmental quality provided.

Figure 1 shows the factors influencing total energy use in buildings. The latter three factors, related to human behaviour, can have an influence at least as great as the former three. The completed EBC research project, 'Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods', has analyzed all six factors together to accurately understand and even to predict building energy consumption due to their

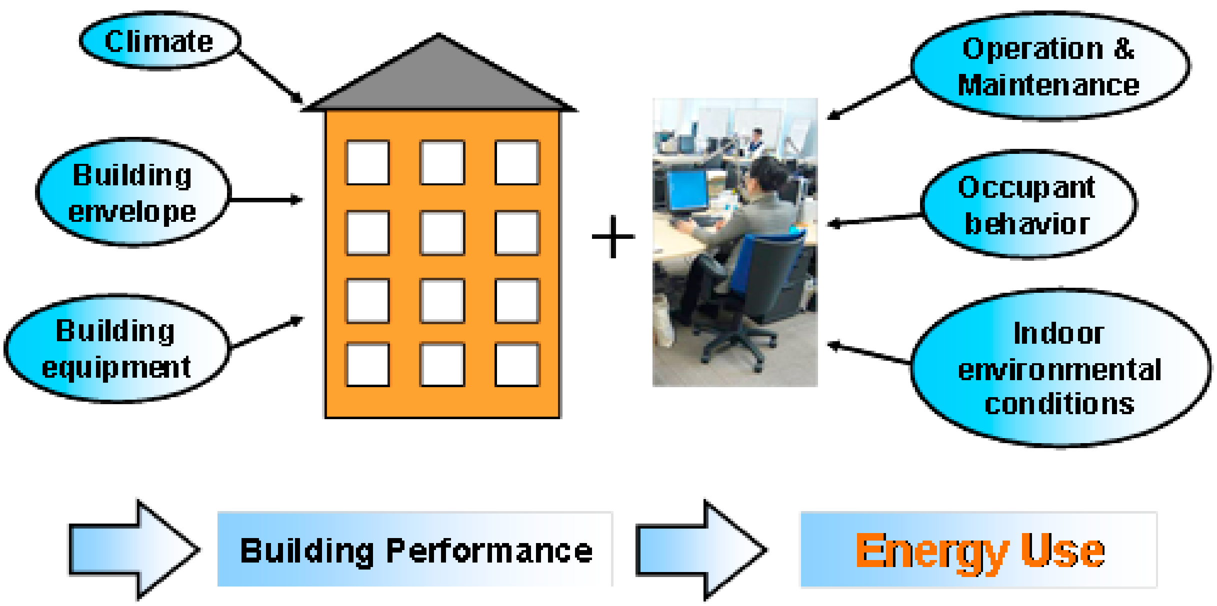

Figure 1. Six factors influencing total energy use in buildings

influences. Previous to this work, the user related aspects and behaviour effects had been presumed from the large spread in energy use for similar or identical buildings, but a distinction between the building-related and the user-related aspects of energy consumption had not been established.

The key outcomes of the project are:

1. Uniform definitions of building energy use items, including energy system boundary, conversion factors, building end use, and energy performance indicators. These provide a uniform language for comparison and benchmarking of building energy use, as well as three different levels of data collection typologies that can help in the analysis of energy performance and influencing factors.
2. International case studies of offices and residential buildings. Basic information contained in the twelve office case studies includes category, data level, location, gross floor area, number of floors, construction year, air conditioning system, cooling and heating sources. Basic information in the twelve residential case studies includes category, number of floors, floor area, construction year, and data level.
3. A review of state-of-the-art online data collection systems and technologies, which included five online systems from Finland, China, Japan, Germany, and Spain. These systems were analyzed to identify the main features and characteristics of various measurement strategies for online data collection and monitoring systems designed for building energy systems.
4. A report highlighting suitable statistical models to apply for energy use analysis. This contains recommendations about the proper application of the different models as a function of the goal of the analysis. These statistical models have a very high potential for both individual buildings and large building stocks, but it is important to clearly define the goal of the analysis in advance and to ensure the availability of suitable data.
5. Specific methodologies to analyze energy consumption in buildings were developed and applied to get the maximum benefit from the use of simulation models. These methodologies used specific concepts such as sensitivity analysis, uncertainty analysis, and highlighted the importance of model calibration when analyzing an existing building.

Project duration
2008 - 2013 (completed)

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Observer: P.R. China

Further information
www.iea-ebc.org

Project Outcomes

The ultimate goal of the completed EBC research project 'Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods' was to better understand and strengthen knowledge regarding the robust prediction of total energy usage in buildings, thus enabling the assessment of energy-saving measures, policies and techniques. The project studied how six categories of factors influence building energy consumption, so as to develop building energy research, practice, and policy more closely aligned with the real world. These categories include climate, building envelope characteristics, building services and energy systems characteristics, building operation and maintenance, occupant activities and behaviour, and indoor environmental quality. The research was performed on two building types: residential buildings (detached houses and multi-family apartments) and office buildings (large scale high rise offices and small scale offices).

Definition of terms relating to energy use and influencing factors

Inconsistency in the terminology related to building energy use is a serious barrier to understanding the influencing factors and to analysing real energy use. To address this, consistent definitions have been developed

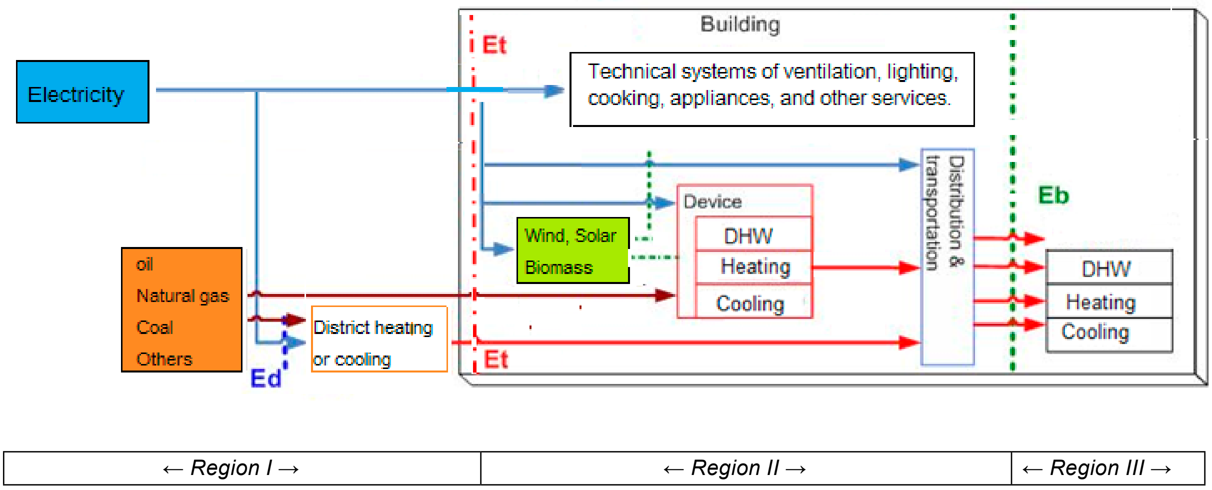


Figure 2. Energy flow and boundaries

concerning the building boundary, energy end uses, energy conservation factors, the six categories of factors influencing energy use, and energy performance indicators. Figure 2 shows the energy flows and boundaries. The building boundary is where energy flows are separated into three components: Eb, Et and Ed, where Eb represents the energy actually required within the building space, Et is the energy delivered to all the technical systems in the buildings, while Ed captures the energy use for space heating, cooling and hot water in district heating and cooling systems. Energy use performance indicators are defined in three ways, which are:

1. only the energy used on the site,
2. the site energy converted to primary energy (energy used for power generation), and
3. the energy use normalised by various factors of floor area, number of persons, and so on.

For the six types of factor influencing energy use, a three-level hierarchy of definitions has been developed. These simple, intermediate and complex levels are related to the type of analysis to be undertaken: the simple level serves large scale statistical analysis; the intermediate level is considered the minimum level for case studies; and the complex level is used for simulation or detailed diagnostics. Table 1 shows the three levels and the six categories of influencing factors. For the research subjects of residential buildings and office buildings in the project, the definitions in each level identify the important items for the different kinds of influencing factor, and the quantitative and qualitative parameters for each item.

Table 1. Three level typology definitions for residential buildings and office buildings

Typology	Energy use data	I	II	III
Level A (Simple, for statistics with large scale datasets) Datasets with small number of data points per building	Annually or monthly	IF1. Climate IF2. Building envelope and other characteristics IF3. Building service and energy system	IF4. Building Operation	
Level B (Intermediate, for case studies)	Monthly or daily	Same categories as Level A, more detail	IF4. IF5. Indoor environmental quality	IF6. Occupant behaviour
Level C: (Complex, simulations or detailed diagnostics)	Daily or hourly			

Note: Levels B and C includes six categories of influencing factors (IF1 to IF6), while a more extensive set of definitions is covered in Level C.

Definitions of energy-related occupant behaviour and modelling

Energy use in residential and office buildings is influenced by the behaviour of occupants in various ways. In order to achieve better understanding of total energy use in buildings, the identification of the relevant driving factors of energy-related occupant behaviour and a quantitative approach to modelling energy-related occupant behaviour and energy use are required. For that, around 100 reports and papers have been reviewed. Energy-related occupant behaviour refers to observable actions or reactions of a person in response to external or internal stimuli, or actions or reactions of a person to adapt to ambient environmental conditions. These actions may be triggered

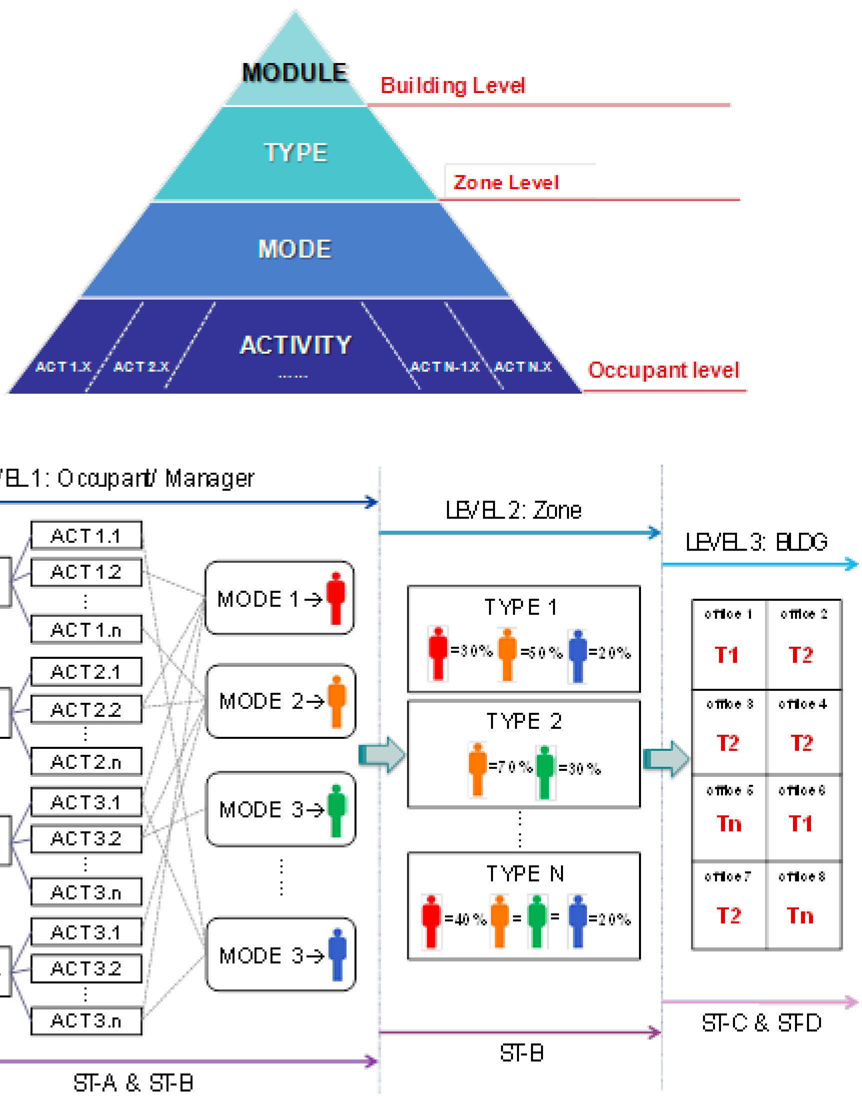


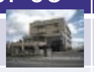
Figure 3. Methodology for occupant behaviour definitions in office buildings

by various driving forces which can be separated into biological, psychological, and social contexts, time, building / installation properties, and the physical environment. Information on occupant presence and activities can be obtained from individual questionnaires or monitoring by zone. Office buildings can be classified at three different levels from a bottom-up perspective as shown in Figure 3. A simplified calculation model of the energy use was developed for a certain item of equipment or system in a certain zone, based on the combination of different behaviour types of different kinds of occupants and their equivalent occupied time, which can be used to the rough evaluation of energy consumption for building services systems in office buildings.

Case Studies of total energy use for analysis and evaluation

Collecting, reviewing and selecting case studies that document and analyze energy use data were a critical aspect of this research. Case studies were developed for thirteen office buildings and twelve residential buildings, and the key results of total energy comparison and occupant behaviour for the buildings were presented

Table 2. Information availability for the office building case studies, in Japan (JP), France (FR), Italy (IT), China (CN), Belgium (BE), and Norway (NO)

	JP01	JP02	JP03	FR01	IT01	CN01	BE01	NO01	NO02
General						 			
Function	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**	**Y**
Architectural	**Y**	**D**	**D**	**Y**	**Y**	**D**	**N**	**N**	**N**
Envelop	**Y**	**N**	**N**	**Y**	**Y**	**Y**	**Y**	**N**	**N**
Weather Data	**Y**	**N**	**N**	**Y**	**Y**	**Y**	**N**	**N**	**N**
Equipment and System Description									
Lighting	**N**	**Y**	**Y**	**D**	**Y**	**N**	**Y**	**N**	**N**
Office App. (Plug-in)	**N**	**Y**	**Y**	**D**	**Y**	**N**	**Y**	**N**	**N**
Ventilation	**N**	**Y**	**Y**	**Y**	**Y**	**D**	**Y**	**N**	**N**
H/ C Source	**N**	**Y**	**Y**	**Y**	**Y**	**D**	**Y**	**Y**	**Y**
Pumps and Fans	**N**	**Y**	**Y**	**Y**	**Y**	**D**	**Y**	**Y**	**Y**

Y: Yes; N: NO; D: Detailed

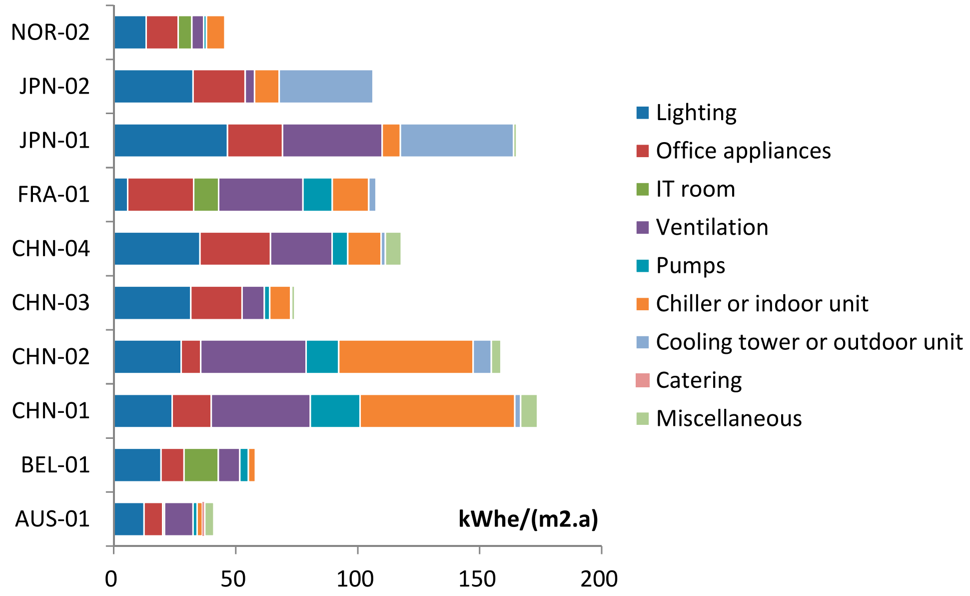


Figure 4. Electricity consumption of 10 case study office buildings

and used as input data for simulation based analyses.

Case studies of nine of the office buildings are shown in Table 2 with a summary of information availability. Electricity use in 10 of the office buildings is presented in Figure 4. The total energy use of the office buildings differs from country to country. For example, heating energy use in Austria, Belgium, Northern China and Norway is similar, while heating energy use in France is very different. Huge differences in electricity uses in the case study buildings are seen in the following systems: air conditioning, ventilation, and lighting, due to the different types of HVAC systems and their operation modes. Further analysis shows large-scale office buildings with floor areas larger than 30000 m2 consume significantly more electricity than smaller office buildings, by comparing the electricity use per square meter. Detailed information on these case study buildings is available in the Final Report (2013).

Data collection systems for the building energy system management

Monitoring is fundamental when aiming to gain better knowledge and understanding of the energy performance of buildings. One of the main activities in this project was to review state-of-the-art online data collection systems and technologies, and to analyze computer programs developed by different countries, to identify the main features and characteristics of online data collection and monitoring systems. Five online data collection systems, from Finland,

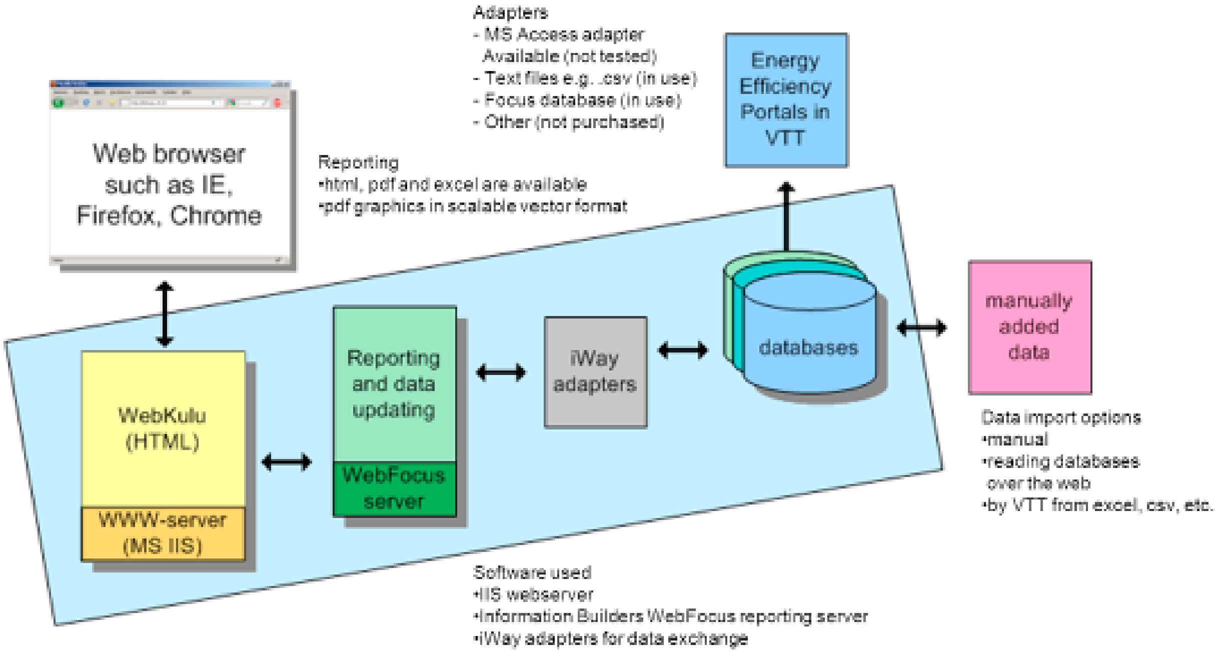


Figure 5. WebKulu technical overview

China, Japan, Germany, and Spain, have been reviewed. All online data collection systems normally require five components: measurements, obtaining external data (such as weather information), data transfer, data analysis, and reporting. To capture the full potential for environmental and energy savings, data provided by smart meters, including energy data and the information about the influencing factors, should be integrated in real time with building automation systems to optimize the use of energy in various building systems. Mass produced sensors often offer cheap and flexible means for measuring both environmental factors and occupation of buildings.

As an example, Figure 5 shows a brief description of an individual online data collection system originally developed in Finland for municipal building owners. User interfaces are created using standard HTML and are therefore compatible with most web browsers.

Statistical analysis of total energy use

Suitable statistical models are important for building energy use analysis and prediction. A database was created in the project to form the basis of statistical analyses, which was divided into two groups in terms of the number of buildings and a number of parameters required to describe buildings. One part of the database is composed of a large number of parameters relating to a single individual building describing its energy behaviour (see the upper-left side of Figure 6), such as hourly and daily energy consumption, outdoor temperature, number of occupants, and so on. Another part of the database covers a large number of buildings, but with each characterised by only a few parameters such as annual energy consumption, floor area, average indoor temperature, and so on.

A further database of 80 Japanese residential buildings supplied to the project is a further example providing an intermediate level of detail. This is composed of 1-minute interval electricity consumption and 5-minute interval gas consumption data for one year for all household equipment. Also, it includes more than 12 characteristic parameters for each house, including heat loss coefficient, air tightness, floor area, number of family members and so on.

An ideal database would be composed of a large number of buildings, each characterised by a large number of parameters (see the upper-right side of Figure 6). But, this would actually be very impractical and expensive to obtain in practice.

To carry out a critical examination of the potential and limitations of applying statistical and predictive inverse models for estimating the energy consumption of buildings and exploring the influencing factors, the experiences of the different project participants were collected and shared. A total of 17 contributions that deal with both residential and office buildings were gathered, and for each contribution the database structure, influencing factors, investigation method and an overall judgment of the potential for the investigation method were summarized. Examining the contributions received, the main goals of the analyses can be divided into two types:

1. Descriptive analysis, including statistical characterization of the subject, benchmarking, identification of driving variables that contributed to energy use, determination of accurate profiles of user behaviour, and so on.

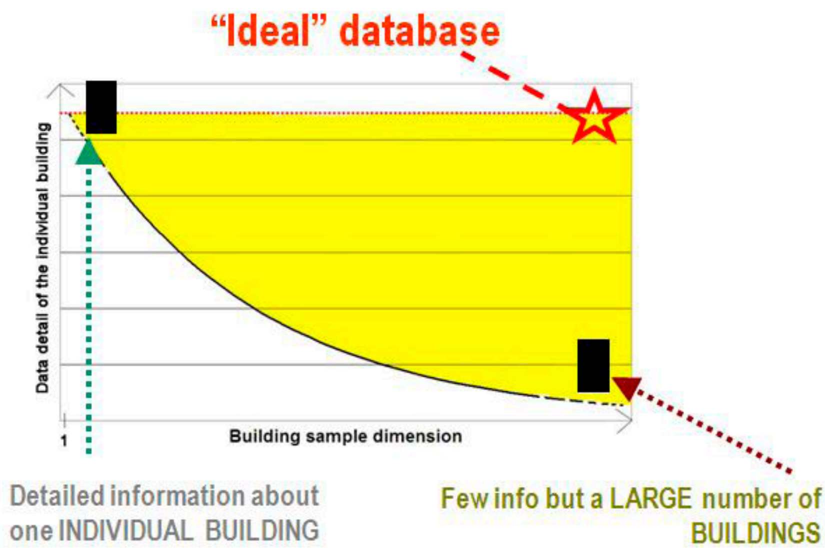


Figure 6. Schematic diagram of information collected in the project database according to building sample dimension and level of detail on individual buildings

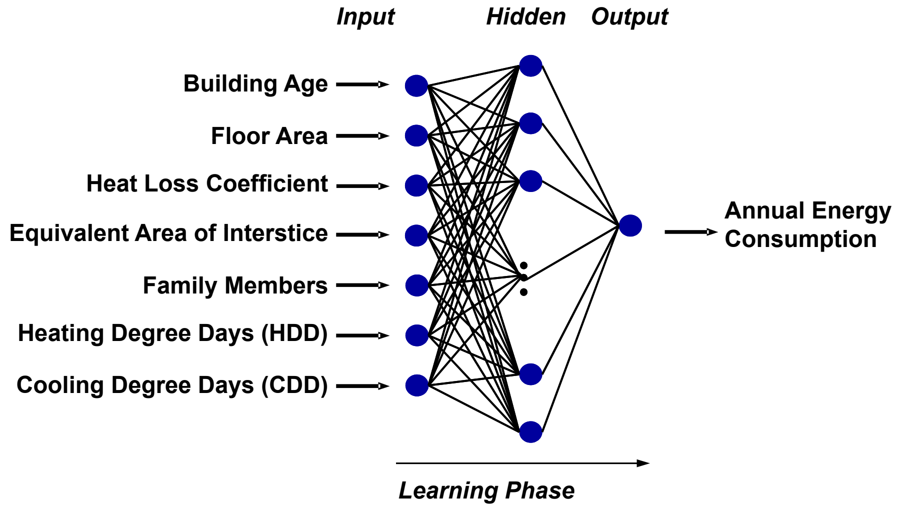


Figure 7. Input and output layers in a neural network model of annual residential building energy consumption

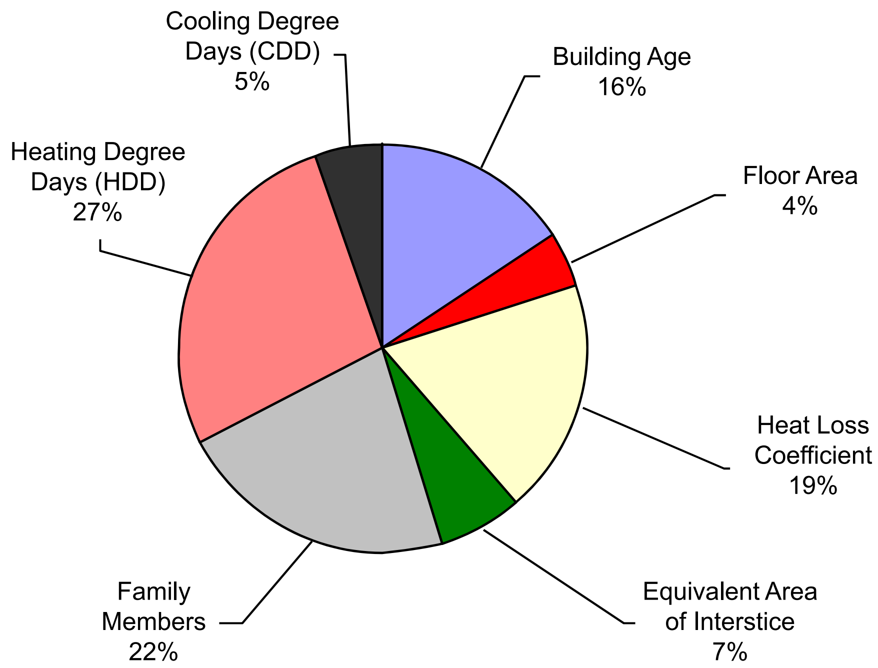


Figure 8. Relative importance of input layers to annual residential building energy consumption according to the results of a neural network model

2. Prediction (forecasting) of energy consumption of the subject. The most commonly used methods are variable base degree-day models, linear regression models, change point models, artificial neural network models, and data mining.

Detailed explanation of these methods is available in the Final Report (2013). As an example, Figure 7 shows an example of an artificial neural network model using the database of 80 residential buildings introduced above. The results shown in Figure 8 reveal that the annual energy consumption can be explained mainly by parameters characterising 'heating degree days' (27%), 'family members' (22%), and 'coefficient of heat loss' (19%).

Energy Performance Evaluation

To obtain more benefit from the use of simulation models for analyzing total energy use in buildings, a number of specific methodologies were developed to complement the use of simulation tools. The approaches taken include sensitivity analysis, uncertainty analysis, and model calibration in order to get more reliable results and to adapt the presentation of the results to the needs of specific users of the simulation tools. A requirement for more realistic consideration of the impacts of building occupants has also emerged from the application of these methodologies. Some examples of energy performance evaluation and its application are as follows:

1. For analyzing the effect of the six factors on energy use, sensitivity analysis has been carried out by running different simulation models on a number of cases by three participating countries. Figure 9 shows the results of the effects of lifestyle changes on residential energy use, in Japan, which reveals that lifestyle changes can save more energy than increased thermal insulation.

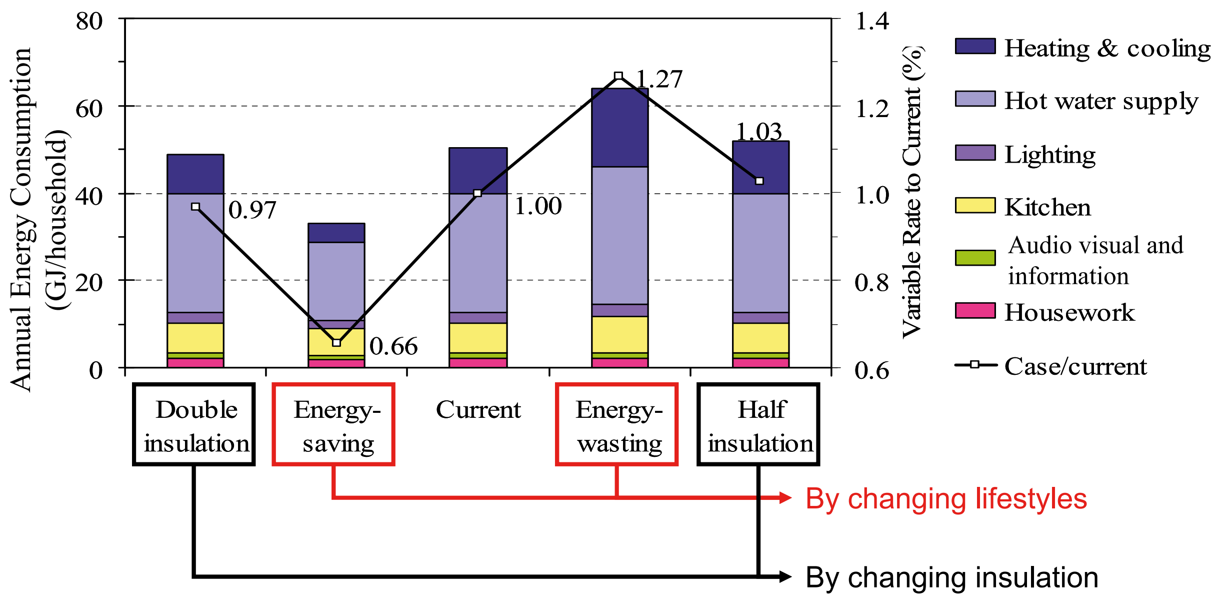


Figure 9. Analysis of the effect of lifestyle change on residential energy use

2. A simulation methodology targeting the design of residential buildings was developed in the project. It is based upon the a priori realization of a large number of simulations of typical cases (generic buildings) followed by the identification of a simplified regression model expressing performance in terms of the dominating parameters. An uncertainty can be attributed to each parameter and the final performance then given as a range around a central value.
3. Monte Carlo simulation, which is based on performing multiple model evaluations with probabilistically selected model inputs, was applied to determine the uncertainty in the model output (prediction) and to perform sensitivity analysis. A detailed description of its application for energy performance evaluation is presented in the Final Report (2013).

Conclusions

This project has contributed to a better understanding of how to robustly analyze and predict the total energy use in buildings, thus enabling the improved assessment of energy–saving measures, policies and techniques. Definitions of terms related to energy use and the influencing factors of building energy use have been developed for offices and residential buildings, providing a uniform language for building energy performance analysis. On this basis, a database of case study buildings in different countries has been established, and the building energy use and influencing factors have been analysed. Statistical models for national or regional building energy data including the influence of occupant behaviour have been summarized, to determine the capabilities and limitations of statistical tools to better describe energy use in buildings and the main factors that affect the energy end use in buildings. Methodologies to predict total energy use in buildings and to assess or evaluate the impacts of energy saving policies and techniques have also developed.

Project Participants

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Finland	VTT Technical Research Centre of Finland Helsinki University of Technology
France	CETHIL, INSA Lyon ENTPE
Germany	Karlsruhe Institute of Technology
Italy	Politecnico di Torino
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Portugal	University of Porto Portuguese Energy Agency University of Coimbra
Spain	International Centre for Numerical Methods in Engineering
USA	ALawrence Berkeley National Laboratory Sustainable Energy Partnerships

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EBC and the IEA

The International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an international energy programme. A basic aim of the IEA is to foster international co-operation among the 29 IEA participating countries and to increase energy security through energy research, development and demonstration in the fields of technologies for energy efficiency and renewable energy sources.

The IEA Energy in Buildings and Communities Programme

The IEA co-ordinates international energy research and development (R&D) activities through a comprehensive portfolio of Technology Collaboration Programmes. The mission of the IEA Energy in Buildings and Communities (IEA EBC) Programme is to develop and facilitate the integration of technologies and processes for energy efficiency and conservation into healthy, low emission, and sustainable buildings and communities, through innovation and research. (Until March 2013, the IEA EBC Programme was known as the IEA Energy in Buildings and Community Systems Programme, ECBCS.)
The R&D strategies of the IEA EBC Programme are derived from research drivers, national programmes within IEA countries, and the IEA Future Buildings Forum Think Tank Workshops. These R&D strategies aim to exploit technological opportunities to save energy in the buildings sector, and to remove technical obstacles to market penetration of new energy efficient technologies. The R&D strategies apply to residential, commercial, office buildings and community systems, and will impact the building industry in five areas of focus for R&D activities:

- Integrated planning and building design
- Building energy systems
- Building envelope
- Community scale methods
- Real building energy use

The Executive Committee

Overall control of the IEA EBC Programme is maintained by an Executive Committee, which not only monitors existing projects, but also identifies new strategic areas in which collaborative efforts may be beneficial. As the Programme is based on a contract with the IEA, the projects are legally established as Annexes to the IEA EBC Implementing Agreement. At the present time, the following projects have been initiated by the IEA EBC Executive Committee, with completed projects identified by (*):

Annex 1:	Load Energy Determination of Buildings (*)
Annex 2:	Ekistics and Advanced Community Energy Systems (*)
Annex 3:	Energy Conservation in Residential Buildings (*)
Annex 4:	Glasgow Commercial Building Monitoring (*)
Annex 5:	Air Infiltration and Ventilation Centre
Annex 6:	Energy Systems and Design of Communities (*)
Annex 7:	Local Government Energy Planning (*)
Annex 8:	Inhabitants Behaviour with Regard to Ventilation (*)
Annex 9:	Minimum Ventilation Rates (*)
Annex 10:	Building HVAC System Simulation (*)
Annex 11:	Energy Auditing (*)
Annex 12:	Windows and Fenestration (*)
Annex 13:	Energy Management in Hospitals (*)
Annex 14:	Condensation and Energy (*)
Annex 15:	Energy Efficiency in Schools (*)
Annex 16:	BEMS 1- User Interfaces and System Integration (*)
Annex 17:	BEMS 2- Evaluation and Emulation Techniques (*)
Annex 18:	Demand Controlled Ventilation Systems (*)
Annex 19:	Low Slope Roof Systems (*)
Annex 20:	Air Flow Patterns within Buildings (*)
Annex 21:	Thermal Modelling (*)
Annex 22:	Energy Efficient Communities (*)
Annex 23:	Multi Zone Air Flow Modelling (COMIS) (*)
Annex 24:	Heat, Air and Moisture Transfer in Envelopes (*)
Annex 25:	Real time HVAC Simulation (*)
Annex 26:	Energy Efficient Ventilation of Large Enclosures (*)
Annex 27:	Evaluation and Demonstration of Domestic Ventilation Systems (*)
Annex 28:	Low Energy Cooling Systems (*)
Annex 29:	Daylight in Buildings (*)

Annex 30: Bringing Simulation to Application (*)
Annex 31: Energy-Related Environmental Impact of Buildings (*)
Annex 32: Integral Building Envelope Performance Assessment (*)
Annex 33: Advanced Local Energy Planning (*)
Annex 34: Computer-Aided Evaluation of HVAC System Performance (*)
Annex 35: Design of Energy Efficient Hybrid Ventilation (HYBVENT) (*)
Annex 36: Retrofitting of Educational Buildings (*)
Annex 37: Low Exergy Systems for Heating and Cooling of Buildings (LowEx) (*)
Annex 38: Solar Sustainable Housing (*)
Annex 39: High Performance Insulation Systems (*)
Annex 40: Building Commissioning to Improve Energy Performance (*)
Annex 41: Whole Building Heat, Air and Moisture Response (MOIST-ENG) (*)
Annex 42: The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems (FC+COGEN-SIM) (*)
Annex 43: Testing and Validation of Building Energy Simulation Tools (*)
Annex 44: Integrating Environmentally Responsive Elements in Buildings (*)
Annex 45: Energy Efficient Electric Lighting for Buildings (*)
Annex 46: Holistic Assessment Tool-kit on Energy Efficient Retrofit Measures for Government Buildings (EnERGo) (*)
Annex 47: Cost-Effective Commissioning for Existing and Low Energy Buildings (*)
Annex 48: Heat Pumping and Reversible Air Conditioning (*)
Annex 49: Low Exergy Systems for High Performance Buildings and Communities (*)
Annex 50: Prefabricated Systems for Low Energy Renovation of Residential Buildings (*)
Annex 51: Energy Efficient Communities (*)
Annex 52: Towards Net Zero Energy Solar Buildings (*)
Annex 53: Total Energy Use in Buildings: Analysis and Evaluation Methods (*)
Annex 54: Integration of Micro-Generation and Related Energy Technologies in Buildings (*)
Annex 55: Reliability of Energy Efficient Building Retrofitting - Probability Assessment of Performance and Cost (RAP-RETRO) (*)
Annex 56: Cost Effective Energy and CO_2 Emissions Optimization in Building Renovation
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Annex 59: High Temperature Cooling and Low Temperature Heating in Buildings
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Annex 70: Energy Epidemiology: Analysis of Real Building Energy Use at Scale

Working Group - Energy Efficiency in Educational Buildings (*)
Working Group - Indicators of Energy Efficiency in Cold Climate Buildings (*)
Working Group - Annex 36 Extension: The Energy Concept Adviser (*)

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